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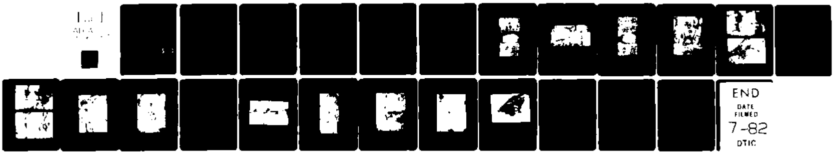

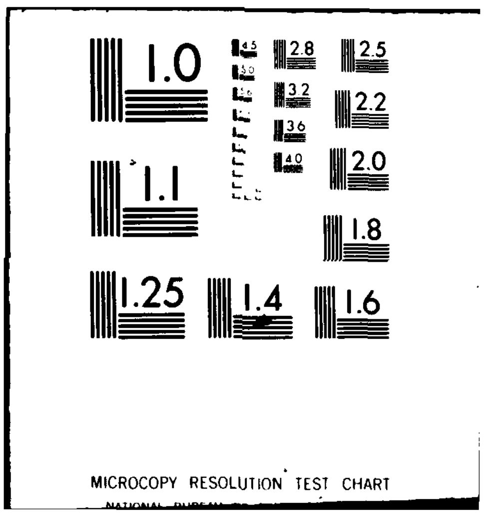
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ANALYSIS OF LONG BONE AND VERTEBRAL FAILURE PATTERNS

UNIVERSITY OF FLORIDA
GAINESVILLE, FL 32610

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18. SUPPLEMENTARY NOTES

Material in this report was presented at the Review of Air Force Sponsored Basic Research in Environmental Physiology and Biomechanics, San Antonio, TX, March 15-17, 1982.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Spinal column, impaction, scanning electron microscopy, light microscopy, intervertebral discs

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Baboons were dropped vertically from four feet above the ground. The vertebral columns were examined with scanning electron microscopy and light microscopy six months and six years post-impaction. Lesions observed were separation of the cartilaginous end plate from the vertebral body and fragments of bone concentrated above the nucleus pulposus. The end plate separation appears to heal but the damage to the vertebral bodies in association with the nucleus pulposus may lead to disc narrowing and osteophytes some time subsequent to the impaction.

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I. INTRODUCTION

During the previous two years of this study, the effects of vertical compressive loading on elements of the spinal column have been examined. When the vertebral body is tested alone, the trabecular bone responds to compressive loading by bending or fracture. (Eurell and Kazarian, 1982) Upon addition of an intervening intervertebral disc to the test unit, the overall severity of damage to the bony structures of the vertebral body is decreased. Fractures of the cartilaginous end plates, displacement of nuclear material into the vertebral bodies, and/or trabecular bone fragments present in the disc has been observed (Eurell, 1981). This work is supported by previous studies which showed that spinal units subjected to compressive loading failed by end plate or vertebral body fracture (Percy, 1957). The fractures were most common in the upper lumbar level, and the fracture pattern varied with the condition of the disc.

The purpose of this research project was to study the effects of vertical impaction on the intact spinal column of baboons.

II. MATERIALS AND METHODS

Vertebral columns from four baboons which were dropped vertically from four feet above the ground were examined following necropsy. The columns were shipped to Dr. Eurell from Wright-Patterson AFB. Samples received were from two baboons sacrified six months post-impaction (PI), (G74 and G84) one baboon sacrificed six years PI (E34), and one control (G30).

The vertebral columns were sectioned mid-sagittally and fixed in 10% neutral buffered formalin. Following fixation, a slab from the column was divided into smaller units and processed for scanning electron microscopy (SEM). Additional portions of the column were processed for light microscopy (LM).

The SEM samples were etched with the modified Boyde technique (Boyde, 1972) dehydrated, critical point dried, and coated with gold palladium to reduce charging. Samples were scanned at 15-20kV in a scanning electron microscope and appropriate photomicrographs were recorded.

The LM samples were decalcified by the sodium citrate-formic acid method, dehydrated, and embedded in paraffin - plastic embedding material. Sections were cut on a rotary microtome and stained with hematoxylin and eosin. These sections were observed with routine transmitted light microscopy and polarized light microscopy.

III. RESULTS AND DISCUSSION

Scanning Electron Microscopy

Control (G30)

Fragments of bone were present on the cut surface of the SEM samples. (Fig. 1) These fragments were homogeneously scattered across the surface and were thought to be due to the sawing procedure.

A Schmorl's node was observed at L_{2-3} (Fig. 2). A clear pathway from the nucleus pulposus through the cartilaginous end plate into the vertebral body was present. Schmorl's nodes are frequently found at necropsy (Vernon-Roberts, 1976), and the presence of this lesion indicates that trauma has occurred to the spinal unit.

Also present were smooth channel-like areas in the cartilaginous end plate near the nucleus pulposus. These channels were more numerous in impacted animals (see below), and may be trauma related. The channels are under further investigation with light microscopy.

The cartilaginous end plate appeared to be tightly bonded to the underlying bone of the vertebral body.

Six-months post-impaction (G74 and G84)

A concentrated area of fractured trabecular and debris was noted in the 6 month P-I animals. This area was observed immediately above the nucleus pulposus (Fig. 3) or just anterior to it (Fig. 4). The lesions were more prominent in the lower thoracic and upper lumbar regions which is supported by Perey's findings (1957). The debris in the hematopoietic spaces appears to be bone fragments, but it is under investigation with light microscopy.

Trabecular microfractures were present, but they were few in number (1 to 3 per vertebral body). The microfractures in figures 5 and 6 appear

Figure 1. SEM of caudal disc region of control animal. Fragments scattered across the sample surface are preparation artifacts. G30 L_{3-4}.

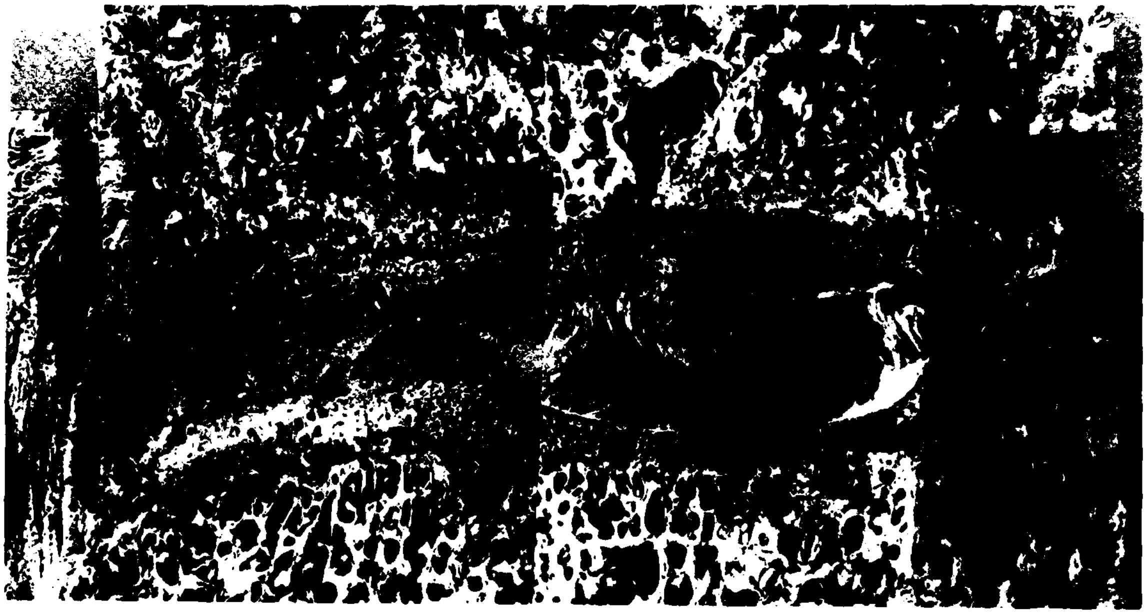

Figure 2. SEM of disc area. A Schmorl's node is present at S. G30 L_{2-3}.

Figure 3. SEM of caudal disc region. The arrows indicate a concentrated area of fractured trabeculae and debris over the nucleus pulposus. G74 L_{1-2}.

Figure 4. SEM of the caudal end zone of L_3 just anterior to the nucleus pulposus. Note concentration of debris in this region. G74 L_{3-4}.

Figure 5. SEM of end zone near disc. Healed microfracture is present. G74 L_3.

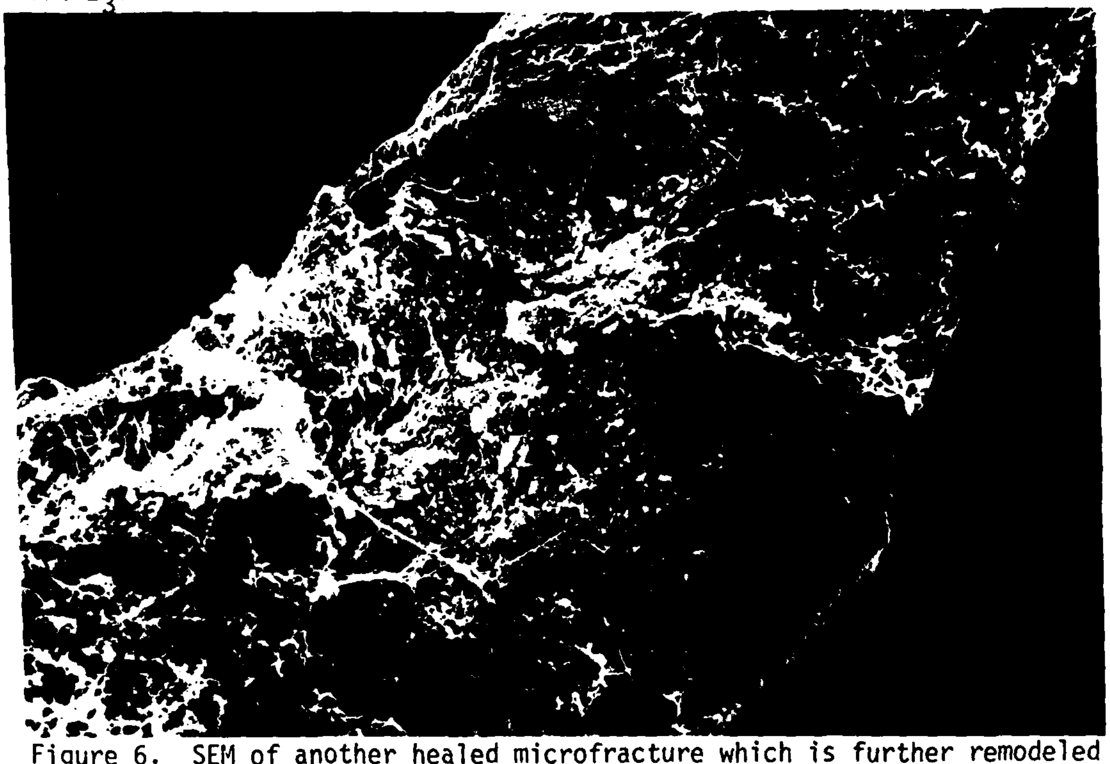

Figure 6. SEM of another healed microfracture which is further remodeled than the one above in figure 5. G84 T_{12}-L_1.

to be healed but other microfractures (Figs. 7 and 8) were still open indicating that the fractures were at different stages in the remodeling process and probably did not occur simultaneously. The location of the microfractures near the end plate and in trabecular with a vertical direction corresponds to work reported by Hansson and Roos (1981 a and b). Frost (1973) suggests that such microfractures occur as a result of normal physical activity and _in vitro_ testing by Nachemson and Elfström (1970) supports this.

In conclusion, it is likely that some of the trabecular microfractures were a result of normal physical activity, however the concentrated areas of fractured trabeculae and debris above the nucleus pulposus are probably a result of the verticle impaction sequence.

Gaps between the vertebral body and cartilaginous end-plate were observed in all samples. These gaps were bridged by strut-like structures (Fig. 9). Inoue (1981) has shown that the cartilaginous end plate has no fibrillar connection with the underlying bone of the vertebral body in man. This lack of interconnection may result in biomechanical weakness in this region, and resultant end-plate separation following excessive horizontal stresses as described by McNab (1977). The vertical struts in the gap region of the baboon may represent an attempt at healing of an earlier separation between the end plate and vertebral body. The tissue comprising the struts is being further examined with light microscopy to determine its composition.

The granular appearance of the cartilaginous end plates was often interrupted with smooth channel-like areas (Fig. 10). These channels were observed in the control animal but seemed more numerous in the impacted animals. The channels appeared to concentrate around the nucleus pulposus. The channels may represent: 1) remnants of vessel pathways from early in

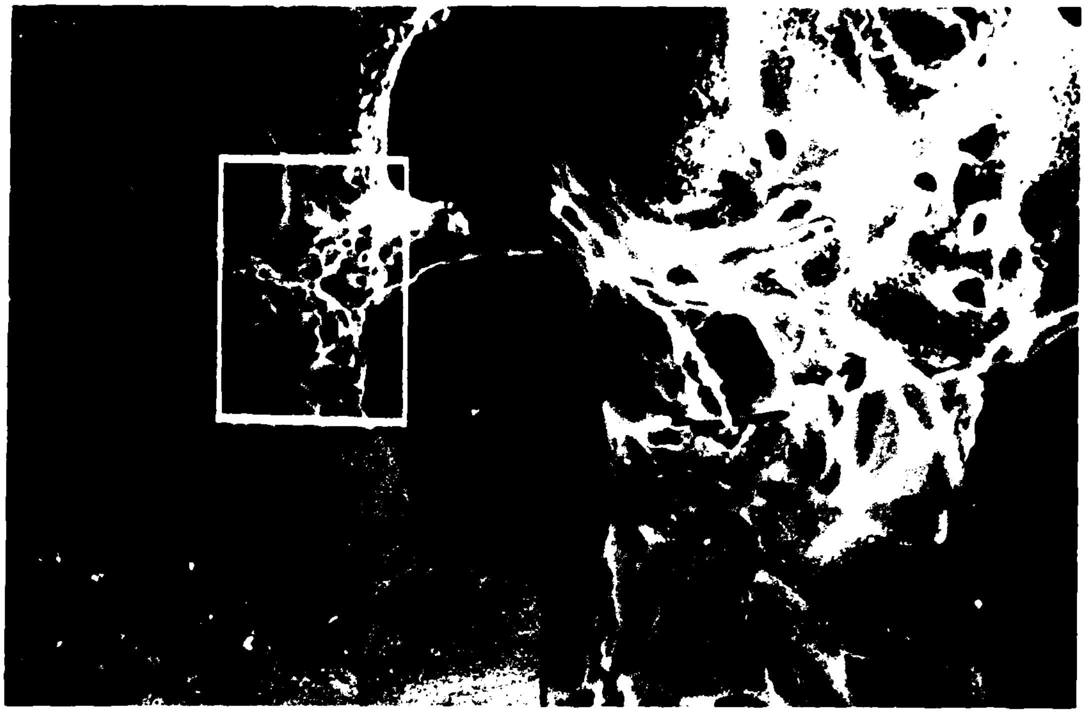

Figure 7. SEM of an open microfracture which occurred at 90^{o} to the disc. G74 T_{12}-L_{1}.

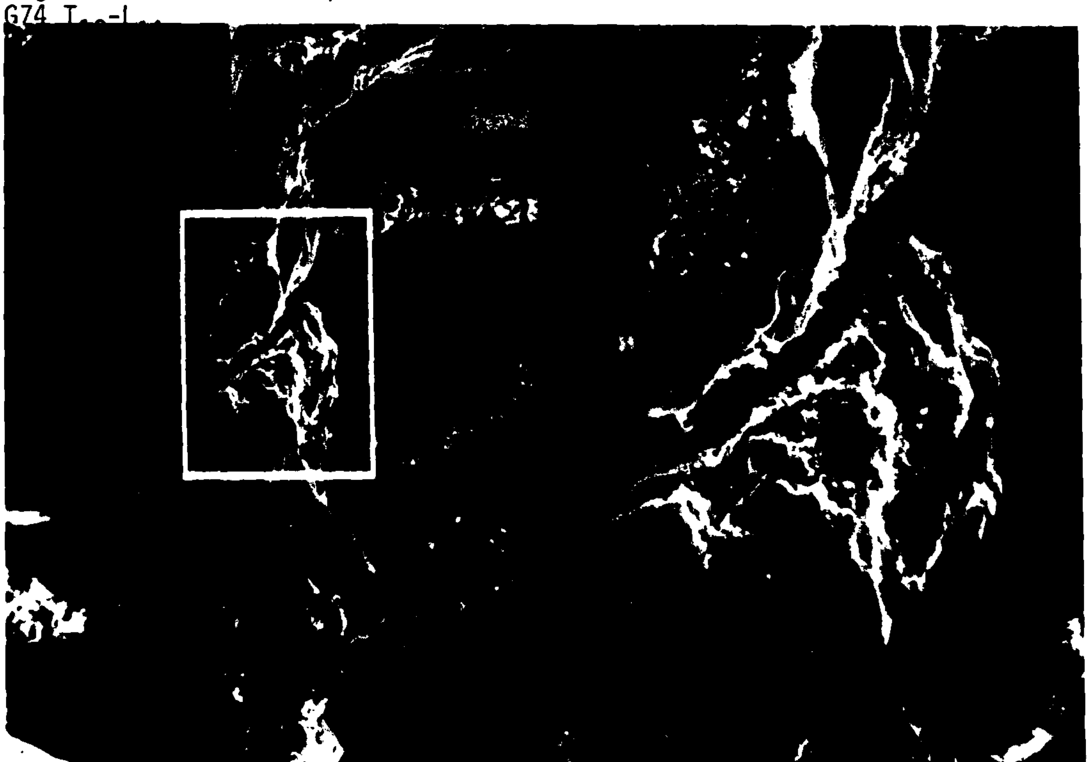

Figure 8. SEM of an open microfracture which occurred at 45^{o} to the disc. G74 T_{12}-L_{1}.

Figure 9. SEM of end plate junction with vertical strut-like structures. G84 L_3.

Figure 10. SEM of end plate junction with smooth channels between the vertebral body below and disc above. G84 T_{1-2}.

development (similar to vessels that cross the neonatal equine growth plate of long bones), 2) remnants related to the embryologic notochord (since they seem to concentrate around the nucleus pulposus), or 3) small, partial Schmorl's nodes caused by the leakage of disc material into the growth plate as a result of the vertical impaction.

Six-year post-impaction (E34)

The overall height of the individual disc spaces in this animal was decreased (Fig. 11) compared to the 6 month P-I animals. The anterior margins of the vertebral bodies had numerous osteophytes which often bridged the intervertebral space (Fig. 12). Endplate channels were also noted as seen in figures 13 and 14.

A few scattered, healed trabecular microfractures were present (Fig. 15). Due to the number (less than 5 per section) the fractures were considered insignificant.

Light Microscopy

Control (G30)

The vertebral column of the control animal appeared normal with light microscopy except for chondrification of the nucleus pulposus at T_{11-12}. Eosinophilic channels were noted crossing the cartilaginous endplate and they probably correspond to the channels observed with SEM.

Six-year post-impaction (E34)

Regions of basophilic, dense trabecular bone were present at the anterior margin of the vertebral body. This bone resembles woven bone when examined with polarizing microscopy, and is probably active bone which is forming the

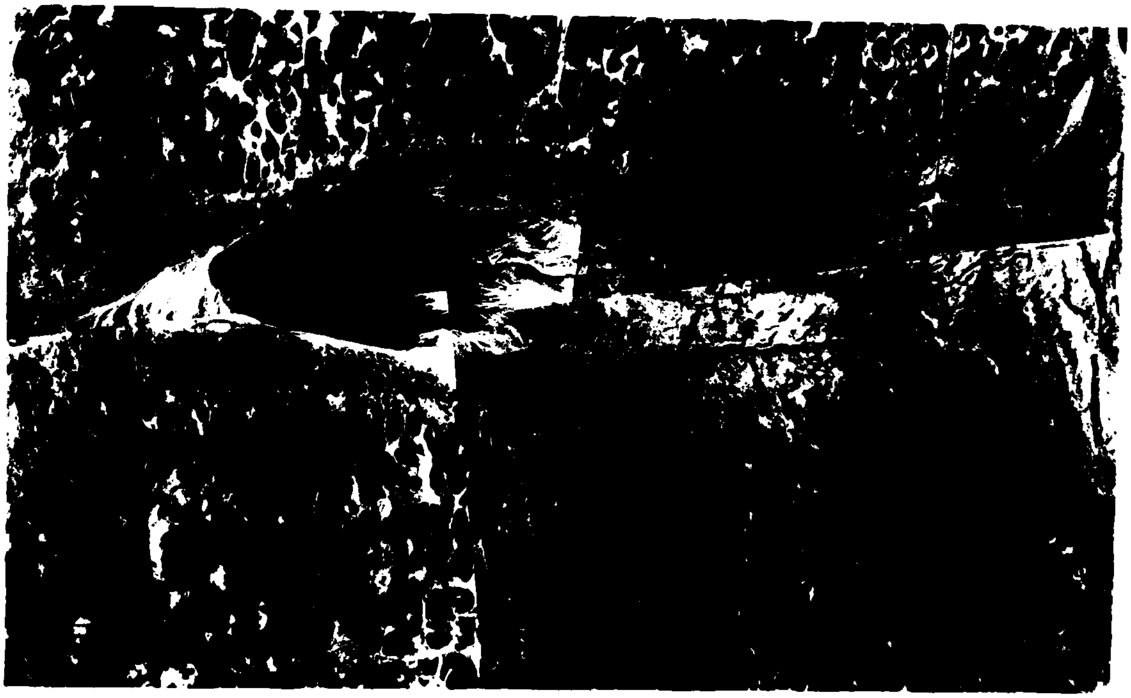

Figure 11. SEM of disc region. Note decreased disc height. E34 L_{2-3}.

Figure 12. SEM of anterior disc. Note osteophytes. E34 T_{12}-L_1.

Figure 13. SEM of caudal disc. Note channel in end plate. E34 T_{5-6}.

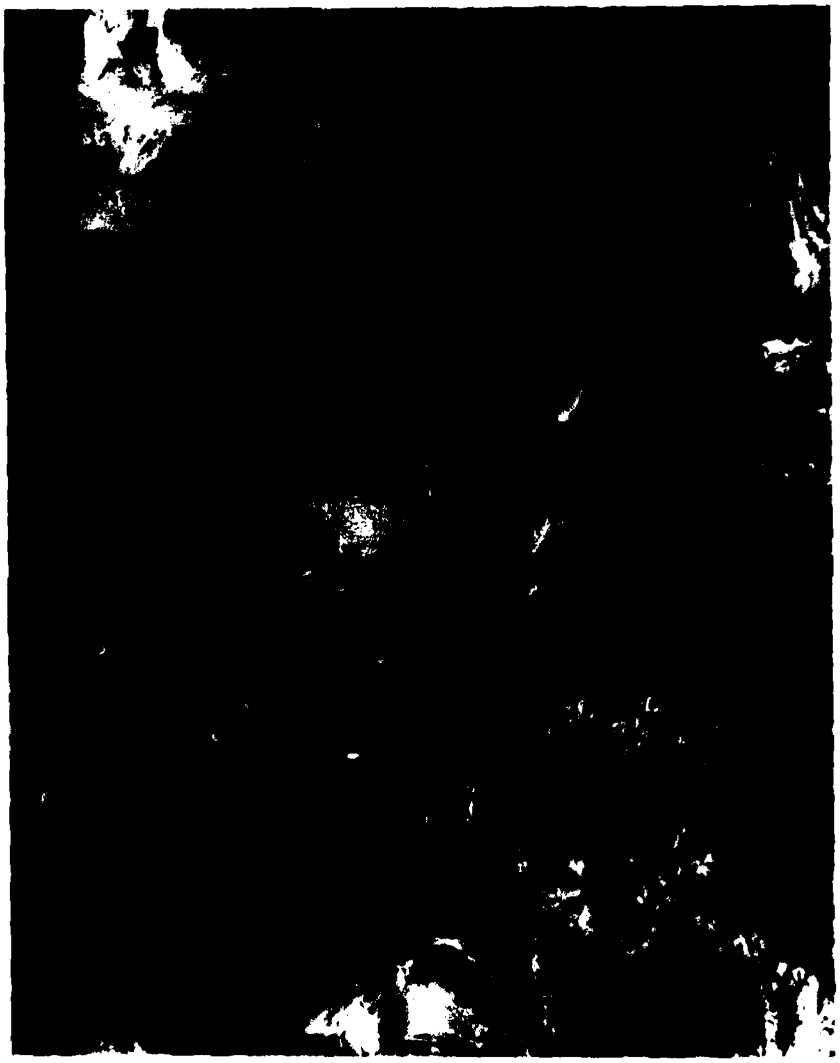

Figure 14. Higher magnification SEM of channel in figure 13. E34 T_{5-6}.

Figure 15. SEM of healed microfracture. Note microcallus. E34 L_{3-4}.

osteophytes present along the anterior margin.

Eosinophilic channels were present in the cartilaginous end plates extending from the disc to the vertebral body. Chondrocytes were present in the matrix of the channels. At least one channel contained necrotic fragments of uncertain origin near the disc.

Regions of separation of the end plate from the vertebral body were noted, but they did not extend entirely across the end plate.

Evaluation of Lesions

In this preliminary study, without control animals of the same age as each of the impacted groups, it is difficult to assess which and/or how much of the changes are ageing related. It appears that the shear separation between the cartilaginous endplate and vertebral body may heal itself and be of no clinical significance.

On the other hand, the region of fractured trabeculae above the nucleus pulposus and the channels through the cartilaginous endplates may be significant. The area of fractured trabeculae may indicate a collapsed region of the vertebral body which allows the disc to bulge into this area and the disc space to narrow. The channels may cause a "leaky disc" phenomenon with a loss of disc material into the surrounding tissue, also contributing to decreased intervertebral space. The pathologic consequences of narrowed intervertebral spaces have been listed by Vernon-Roberts (1976) as: 1) anterior and lateral marginal osteophytes, 2) decreased range of movement in the affected segments, 3) forward tilting of the vertebral bodies, possibly leading to kyphosis, and 4) abnormal stresses on the posterior intervertebral joints. Marginal osteophytes were observed in this study.

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V. PUBLICATIONS

One is planned pending more data to be acquired shortly.

VI. PROFESSIONAL PERSONNEL ASSOCIATED WITH THE RESEARCH EFFORT

Dr. Jo Ann C. Eurell

VII. INTERACTIONS

a. Presentations

Eurell, J. and L. Kazarian. The quantitative histochemistry of lumbar vertebrae from rats following flight in space. International Society for the Study of the Lumbar Spine. Paris, France, May 16-21, 1981.

Eurell, J. Analysis of long bone and vertebral failure patterns. Review of Air Force Sponsored Basic Research in Environmental Physiology and Biomechanics. San Antonio, TX, March 15-17, 1982.

b. Visits to Air Force Laboratories

To Wright-Patterson AFB, AMRL/BBD, June 21-26, 1981.

VIII. INVENTIONS AND PATENTS

None.

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